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CONCRETE IN WATERWORKS STRUCTURES, WITH SPECIAL REFERENCE TO ITS RESISTANCE TO WEATHERING AND METHODS OF REPAIRING IT¹

BY RUDOLPH J. WIG

The use of concrete in waterworks structures is very old and it is not the intention of the author to present a historical digest of this usage but to give special, though brief, consideration to the causes of disintegration of concrete exposed to the elements; proper methods of fabrication of concrete to obtain the best results where exposed to weathering or elemental action; and methods of repairing disintegrated concrete.

As in the development of all great industries, concrete is passing through its cycle. This is the concrete age and there are few engineers who have not the utmost confidence in this material and in their ability to use it in forming all manner of permanent structures. The idea of reliability has become so strongly intrenched that failures of concrete are invariably explained as caused by the use of some inferior component element or improper method of fabrication. The possibility that concrete may fail as a structural material is not recognized.

It is the author's belief that while concrete as best fabricated to-day is a structural material capable of furnishing satisfactory results under almost all known service requirements, there are some conditions under which its usage is unsafe or can at best be considered only experimental. The statements which follow, though not illustrated by specific examples, are based upon both laboratory and field investigations, mainly the latter, resulting from a careful examination and collation of data pertaining to several hundred structures.

The author has examined during the past few years several score of concrete structures in various stages of failure. There is unmistakable evidence that, under some commonly considered normal exposure conditions, some of the very best concrete is rapidly disintegrating. There is further evidence that some cements which

¹Read at the Richmond Convention, May 10, 1917.

meet all the requirements of standard specifications, after several years show marked indications of deterioration in concrete and under certain exposure conditions completely disintegrate. This information is brought to you, not with a desire to create uncertainty in your minds regarding concrete but rather to impress you with the fact that concrete has its limitations and that only by the greatest care, study, and investigation of conditions affecting any particular work can you expect permanent structures.

The divergent views expressed by those skilled in the art as to the general quality of concretes fabricated under specified conditions from certain given materials or exposed to elemental action in a given situation has caused confusion among engineers and investigators. As a consequence, the engineer has more or less pioneered for himself, finding abundance of authority in the committee reports of engineering societies which contain the most general statements on the universal successful application of concrete to all structural purposes provided certain simple rules are followed. These divergent views are due mainly to habitual generalizations made from limited experience, without giving proper weight and recognition to all of the variables which affect the ultimate quality of the product.

The author has recently been interested in a number of investigations of considerable magnitude. Two of these have involved the careful examination of many structures widely scattered over the United States. Had these investigations been more confined in scope several divergent conclusions might have been reached, depending upon the particular structures selected. Conclusions would have been correct in each case, but only of limited rather than of broad scope. The conditions for satisfactory structures in one district would result in failure in the other. The author feels, therefore, that while certain general rules should be followed, there is no patent formula for concrete which has general and widespread application and will invariably insure success under any and all conditions.

Fortunately, most of the cements made in America are satisfactory so far as we know, most of the natural aggregates make good concretes and the majority of the failures appear to be due to improper practices which can be improved. Failures sometimes occur from natural causes, the possibility of which has been overlooked by the designing engineer because the facts have not been made available to him or he is pioneering. Other failures are due to the ignorance

of the over-wise, self styled "practical" man who has dabbled with cement since babyhood and will not carry into effect the wishes of his superiors relative to details of fabrication because he thinks he knows far more than they. A large percentage of all failures are due to still another cause. They are the result of negligence on the part of the engineer in charge in not giving sufficient attention to what he considers the minor details.

CAUSES OF DETERIORATION OF CONCRETE

The causes of deterioration and occasional failure of concrete exposed to weathering or severe elemental action, generally are the neglect of details which by many are considered of minor importance. If time and circumstances would permit, structures would be cited illustrating actual deterioration or failure which has occurred from each of the following causes, enumerated in the order of importance as based on the observations of the author.

1. "*Pioneering*" or the use of unproven methods and designs.

The use of fluid or watery consistencies in mixing the concrete is the most serious of all abuses. Such concrete may have a good appearance when the forms are first removed but in a short time a variety of ailments develop, all of which are of a malignant character, making the concrete vulnerable to frost action and erosion. It may reduce the strength to a half or quarter of the normal; increase the porosity; cause separation of the mortar from the aggregate; produce concrete of variable density in different parts of the structure; and permit the formation of large quantities of laitance.

The location of embedded plums or manstones too near the exposed surfaces of the concrete results in deep erosion if the surface becomes slightly abraded.

Concrete is made subject to rapid deterioration by the use of designs or methods which do not permit the elimination of prominent construction seams; which require the use of fluid mixtures; which do not allow for removal of laitance, and which otherwise prevent proper workmanship.

There are numerous structures throughout the country which show marked deterioration from one or a combination of several of the above causes. Total failure has occurred in some cases.

2. *Careless workmanship*. This involves inadequate mixing, improper transportation of the concrete from mixer to forms, incorrect

methods of placing, lack of thorough spading, the use of leaky forms, and lack of care in protecting the green concrete from rapid drying, all of which result in material variation in the quality of the concrete, the formation of sand and stone pockets, separation of the mortar from the coarse aggregates, streaks of voids on the surface and other defects.

Failure to remove the laitance which usually accumulates with wet mixtures at the top of each day's work results in soft, weak sections or seams, which are readily eroded under severe exposure conditions.

Lack of care to prevent the disturbance of the previous day's concrete surface while spading the succeeding lift at the face of the forms causes weak construction seams where erosion can start.

Failure to remove the mortar which has splashed onto the surface of the forms of the succeeding day's lift results in a rough, patchy, and sometimes porous concrete surface.

3. Poor materials. Our knowledge of cements is so limited it is impossible to state in the majority of cases of failure whether the quality of the cement is a contributing factor. Investigations have shown that cements which may be unsound or otherwise inferior according to our standard tests may give wholly satisfactory results in concrete under normal exposure conditions. The converse has also been noted to be true, that some cements meeting the requirements of standard specifications are not wholly satisfactory in concrete under normal exposure. This situation indicates that our present specification is unsatisfactory, for it does not properly classify cements.

Impure or improperly graded sands occasionally account for deterioration or failure. The use of stone screenings containing a large percentage of dust results in a porous concrete which is disintegrated by frost action. The use of soft shales, schists, and similar aggregates which decompose cause rapid deterioration of the concrete.

The above do not cover all the causes of failure but only those of general character and application.

The art of concrete construction is in its adolescence, although developing with great rapidity. It is impossible to enumerate general rules of practice for fabricating a material such as concrete, which is any concoction containing Portland cement, and so circumscribe the statements by limitations on their application that they will, in every case and under all conditions, be correct. It is,

therefore, with considerable hesitation that the author makes the following suggestions. The observance of these suggestions will assist in obtaining an excellent quality of concrete which will in general resist the disintegrating action of the elements. Where the surface will be exposed to unusually severe erosion and frost action it is the opinion of the author that a stone facing should be employed. Under other unusual exposure conditions special treatment may be required. Under less severe conditions of exposure satisfactory results may be obtained without following all of the suggestions here made.

SUGGESTIONS FOR IMPROVING THE QUALITY OF CONCRETE

It would be bold presumption to claim originality or newness for any of the suggestions which follow, although in certain respects somewhat radical changes from current practice are proposed. These are made not from theoretical considerations but from careful field observations of a large number of structures built under varied conditions.

The consistency of the mixture should be quite stiff, preferably such that it can be rammed or tamped with a tamper and yet not so stiff but that it will produce a smooth surface against the forms, just barely showing the board marks when the forms are removed. If the concrete is reinforced a wetter consistency must be used, but any increase in the amount of water used in mixing is at a sacrifice of quality. The use of this stiff or quaking consistency will practically eliminate segregation, it will eliminate or decrease to a minimum the formation of laitance and the prominence of construction seams between days' work, and it furnishes concrete of high strength and low porosity. Its use will automatically necessitate more thorough mixing and more care in placing in order to obtain a presentable face. In fact, this consistency is most desirable from every standpoint but one, and that is cost of proper placing. If used only in the facing of mass work, however, the additional cost on the entire structure may be very slight.

The author realizes that this recommendation, while approved by some, will be considered extreme and radical by many. A recent examination of a large number of structures under severe exposure conditions demonstrates the marked superiority of this particular consistency in every case.

It has been suggested that the evils produced by the use of watery mixtures could be in large measure remedied by wasting the "laitance" or lighter portions of the mix which float to the top of each day's work. If soupy or wet mixed concretes were defective only in the seams or at day's work planes the suggestion would be effective, but soupy concrete is defective through the mass and especially so in the corners and ends of the forms which are usually filled with the lighter portions of the mix.

Thorough mixing results in uniformity in quality, increased strength, increased plasticity, and in a generally improved concrete. There is a certain minimum of mixing required to give maximum strength with any particular set of conditions. The more water used up to a certain limit, the less mixing required. If gravel is used as the coarse aggregate, less agitation is required than with crushed stone under similar conditions. If the mixture is relatively stiff, its plasticity is much increased by thorough agitation. For the best results the actual mixing should never be less than 20 revolutions, requiring about one and a half to two minutes of continuous rotation in the drum of the common type of mixer. Some engineers and contractors are now requiring from two to ten times this amount of mixing.

The sand should be clean, hard, preferably graded, and relatively coarse. The coarse aggregate should also be graded and the maximum particles not too large, 2 inches or less, in the portion of the concrete near the exposed surfaces. In the interior of the mass the use of large size aggregate, 6 to 8 inches, is both desirable and economical. The cement should be carefully inspected and tested. Although all brands are guaranteed to meet the standard specifications some are better than others. Preferably those brands should be selected which are known to run uniform in quality.

Special attention should be given to the details of construction. The possibility of erosion and frost action at construction seams should be minimized by careful squaring of the edges of the green concrete several inches in depth along the face at each lift and the removal of any laitance that has formed.

The concrete should be carefully transported so that there will be little or no segregation and it should be deposited in the forms as near as possible to its final resting place. Long chutes in general should not be used, but where employed the angle in no case should be flatter than 35 degrees to the horizontal. The redistribution of

concrete in the forms should be done by shoveling and not by gravity or shoving. Actual tamping can and should be done if the author's recommended consistency is used, and the surfaces should be spaded and the surface of the form lightly tapped. The thorough working of stiff mixtures increases the density but the soft mixtures cannot be worked very much or segregation and excessive laitance will result.

The above factors are considered minor details by many but they are of major importance in exposed work and should not be neglected.

The designs employed should be such as will, as far as possible, permit the use of stiff concrete mixtures which require thorough working into place and the location of bulkheads at short intervals so as to carry up the work with the fewest number of horizontal construction joints. Sharp angles and corners, which are easily cracked or eroded, should be eliminated wherever possible. Only the absolutely necessary joints should be made at the exposed faces. All steel should be embedded a full 2 inches from the exposed face and if the structure is near sea water additional protection is necessary, depending upon the location and design.

In addition to the important matters discussed above, all factors entering into the fabrication and treatment of the concrete must be given attention in the case of each structure if satisfactory results are to be obtained.

Since concrete is wholly a field fabricated material, the quality obtained is largely dependent upon securing the whole-hearted coöperation of the contractor. The contractor, who is in fact the manufacturer, must thoroughly understand what it is desired to accomplish.

High-grade, intelligent men should be employed as inspectors and a greater number must be used than in the past. Their duties should consist, not exclusively in counting sacks, enumerating the employees of the contractor and measuring the yardage of concrete placed, but in intelligent assistance to the contractor so that he may produce the quality of work desired. Unless the inspection force has been properly schooled and thoroughly understands and appreciates the need for this minute and exacting attention to details any specifications which may be prepared will be entirely vitiated. Furthermore, the inspectors must have the support of their superiors and if possible the confidence of the contractors or their work will not be effective. Too much stress cannot be placed upon the need for intelligent and adequate inspection.

Most contractors desire to furnish the best possible job commensurate with the price which they are paid. Where one neglects to follow instructions it is often because he does not appreciate the importance of these details and looks upon them as unessential.

All the suggestions made above may be summarized in the one recommendation that the most skilled talent obtainable be employed and every precaution possible be taken to obtain density, strength and uniformity in quality of the concrete surface which is to be exposed to severe elemental action. Under certain conditions even the best of concrete will deteriorate unless protected or specially treated.

REPAIRS TO DETERIORATED CONCRETE STRUCTURES

The author was requested to present information on two particular methods of repairing deteriorated concrete, viz., the cement gun and the concrete atomizer. Most of the members of this Association are familiar with the construction and operation of both machines and it will not be necessary to describe them in detail.

The cement gun consists of two compartments, the upper or charging chamber and the lower or discharge chamber, the latter containing a revolving feed wheel and discharge mechanism. In operation a charge of dry sand (not over $\frac{1}{4}$ inch in size) and cement, after being given a preliminary mix, is fed into the upper chamber; when this is closed and air admitted the material falls into the lower chamber where it is automatically stirred and discharged by a feed wheel into a hose. By closing the door between the two chambers and releasing air from the upper chamber, the upper door may be opened and the chamber again charged, thus making the operation continuous. The dry mixture of sand and cement is forced through the hose by air under 40 to 75 pounds pressure. Just before passing through the nozzle of the hose, water is added to the dry mixture in the form of a fine spray from a hollow ring within the nozzle, pierced with holes for the water. The quantity of water is regulated by a valve. Mixture with the water is effected at the nozzle, in transit, and on impact upon the surface being coated.

The concrete atomizer differs from the cement gun in several respects. It handles either mortar or concrete mixtures. All materials, including the water, are mixed in the machine by means of revolving paddles preferably in the presence of steam at a pressure

of about 90 pounds per square inch. After mixing, the concrete is discharged by means of steam at about 40 pounds pressure through a hose to a nozzle which is held several feet from the surface upon which the concrete is to be deposited. It is of a batch type and not continuous in operation.

Both of these machines can be used to apply mixtures through several hundred feet of hose on either vertical or horizontal surfaces.

The cement gun has been on the market for a number of years, during which period it has been used on many structures, often in a more or less experimental manner and with varied results. The uniformity in quality of the mixture applied to a surface depends largely upon the skill of the operator and the character of the surface upon which the coating is being applied. Observations indicate that dense impermeable quality mortar weighing from 150 to 160 pounds per cubic foot can be readily applied to surfaces which are flat or do not have deep recesses or interior angles. In deep recesses, where the mortar is wholly trapped as it is applied and none of the sand can rebound, the mortar may be more or less laminated or seamed with porous sand layers or pockets.

It is believed these defects can be much reduced by special care in manipulation of the apparatus and the use of proper mixtures, consistencies, and air pressures. For the best results on vertical surfaces it is generally considered necessary to apply the mortar in layers not over $\frac{1}{4}$ to $\frac{1}{2}$ inch thick.

The machine is not fool-proof and in the hands of the unskilled will not produce good results. The mortar properly applied adheres well to concrete, brick, tile, and stone surfaces.

The concrete atomizer has been in use for several years. Under favorable conditions it produces concrete of great density, 160 to 170 pounds per cubic foot. Its main superiority over the cement gun lies in the fact that the process of mixing is completed before the concrete passes through the hose, that it handles concrete mixtures and leaner proportions than the cement gun. The uniformity of the product is not so largely dependent upon the method of application. The product of the atomizer adheres well to concrete, brick, tile, and stone surfaces, if properly applied.

It is the author's opinion that both of the machines can be used to repair deteriorated concrete structures. The success of such repairs is largely dependent upon the proper preparation of the eroded or deteriorated surfaces. In general, where deterioration has taken

place, the concrete is soft or of poor quality. If the foundation is not firm, do not expect good adhesion. In such cases it is necessary to provide mechanical anchorage by means of expansion bolts and metal fabric, if permanency is to be assured under severe exposure conditions.

In general it may be stated that although the possibilities of both the cement gun and the concrete atomizer have not been fully developed, it is believed they can be satisfactorily employed under many conditions for repairing deteriorated or eroded concrete surfaces, and if properly handled will produce satisfactory results.

DISCUSSION

FRANCIS E. LONGLEY: We all fully appreciate the importance of the summary that the author has given of this subject of concrete, especially every one interested in the design and construction of concrete structures in connection with water works. He naturally lays great emphasis on the importance of securing intimate mixtures and proper proportions. That, of course, is fundamental, and that depends largely on the energy, honesty and ability of the contractor who is handling the materials.

But assuming that we have concrete perfectly mixed in accordance with the specifications, we will all admit that the worst enemy of good concrete is frost. The action of frost will disintegrate rock of any kind. It is one of the greatest factors in geological changes; and the more porous the rock is, the more rapid is this disintegration due to the action of frost. Similarly we can fairly assume that the more porous concrete is, the more rapid will be its disintegration due to frost action. It naturally follows, therefore, that to make concrete as resistant as possible to the action of frost we ought to make it as impermeable as possible. Impermeable concrete, depends, of course, upon the nature of the mix.

First of all, as we frequently have called to our attention, the constituent materials, the sand and the gravel, must be properly graded and properly proportioned; secondly, and of equal if not of greater importance, we must have plenty of cement in the concrete. In the early days of the manufacture of concrete structures it was customary to reduce the quantities of cement to an absolute minimum on account of the high price of cement; but the relative costs of the different ingredients that go to make up concrete have changed materially in the last twenty years.

The cost of cement used to be too high, and the cost of labor low. These conditions are now exactly reversed. Therefore, it is apparent that we can at quite reasonable cost increase the impermeability and consequently the durability of concrete by making a considerable increase in the percentage of cement in the mixture, which increases not only the impenetrability but also the strength. It is a simple way of arriving at a very desirable end. In the course of the past ten years, the firm to which the speaker belongs has made two such general increases in the percentage of cement in the mixtures used for concrete structures.

J. N. CHESTER: What was said in the paper in regard to the necessity of spading and tamping is certainly in the line of good practice; but does the author of the paper realize that with reinforced concrete, the thin walls that are produced and the frequently deep forms employed render it extremely difficult to carry out his prescription with regard to the spading and tamping? Although the latter is essential, yet on the other hand the drift is rather toward the use of more water in concrete. In a tank recently constructed, the supporting members of the tank were inclined at a slight angle, more for the object of bettering the external appearance than anything else. Realizing that some difficulty would be experienced in dealing with concrete at the bottom, long rods were provided in order that it would be possible to spade and tamp to a much greater extent. The removal of the forms revealed that the upper sides of those inclined members had failed to compact at all and were ragged, necessitating filling afterwards with cement mortar. Again, building a 16-foot basin with walls strongly re-inforced, it was found very difficult to spade and tamp the concrete satisfactorily. Has anybody been able to tamp and spade such thin walls properly and still use concrete of the stiffest consistency?

RUDOLPH HERING: Sometimes light is thrown upon a subject by going to extremes. The information that the author has given is based on the qualities of ordinary water. If sewage is in contact with concrete, sometimes with an acid and sometimes an alkaline reaction, it is very interesting to record its effects on the concrete.

The speaker made an interesting examination in England many years ago of a number of sewage tanks built of or lined with concrete. This confirmed what Major Longley and the author have said, namely,

that the density of concrete is a very important factor in its durability. In the sewage tanks there were a number of places where the deterioration was very apparent, where the acid of the sewage had eaten out the cement; and there were other places where the surface seemed to be just as it was when it was put in years before. A discussion with the superintendent revealed the fact, that those places that were still good had been more carefully troweled, in other words, the surface was quite dense, whereas those places that had deteriorated had not been so dense. Very frequently the surface of concrete is somewhat porous and rough; and it thus gives the sewage a chance to penetrate, and the acid in the sewage to cause the deterioration. That examination gave the speaker the idea for the first time that one of the important requirements in concrete, when used for sewerage purposes, was to produce as dense a surface as possible, and thereby greatly increase the chance for long life of the concrete. This conclusion has since then frequently been verified in the speaker's practice.

FRANK A. BARBOUR: The author states that it is not good practice to spout concrete on an angle less than 30 degrees. The speaker agrees with this, yet on every contract with which he has been connected, where the contractor delivered concrete by the spouting method a flatter angle was proposed. The speaker has permitted an angle of 30 degrees and the concrete was good, but where spouting can only be done at a flatter angle he requires the contractor to use wheelbarrows to deliver the concrete.

The author has made use of the term "erosion" in several places in the paper where its exact meaning is not quite clear, and it is desirable to have his definition of the word. The author will also furnish helpful information if he will give the Association a statement of the latest knowledge regarding the effect of the time of mixing on the plasticity of fresh concrete.

LEONARD METCALF: Perhaps in reply to Mr. Barbour, the author will state also whether the government's studies have included investigation of the necessity for storing cement for longer seasoning than it has sometimes received in large and important work, where very large quantities of cement have been used. Among some engineers in this country that question has been considered one of great importance, as has been the necessity of having very much larger

quantities of cement on hand on the ground, in order to be perfectly certain that the cement be not too fresh and that it be well seasoned.

JAMES W. ARMSTRONG: The speaker would like to ask the author to state his experience regarding the ultimate effect of continual seepage of water through concrete not subject to frost action.

N. T. VEATCH, JR.: There has been a great deal said about the amount of water used, which should not be left simply to personal judgment as to whether the concrete mixture shall be extremely wet, or rather plastic. Has the speaker any figures as to the proper amount of water for different mixtures, that is, in gallons per cubic yard, say?

J. WALDO SMITH: The author of this paper has presented a very complete summary of the recent advance in our knowledge of concrete and his facts and conclusions are recommended to the serious consideration of all users of concrete. The speaker is in full agreement with the main conclusions of the author.

A quarter of a century ago concrete began to replace stone masonry. This early concrete was made with cement which was inferior to the Portland cement which is now being manufactured, largely natural cement. Nevertheless the results were highly satisfactory. In the light of recent experience this seems to have been due to the fact that this concrete was placed in such dry consistency that it had to be rammed very hard in order to compact it into a dense mass. It was deposited in layers only a few inches thick and heavily rammed for a considerable time. The mixture was so dry that only after prolonged heavy ramming did traces of water appear on the surface.

Later it was found that by making concrete of a wetter consistency it could be placed with seemingly satisfactory results at much lower cost. It is only recently that it has been realized that this wetter mixed concrete is a material of a different class from the earlier rammed concrete. Very good concrete may be made with a plastic and even with a soft plastic mix, but it should be realized that even at its best such concrete does not belong to the same class as rammed or otherwise mechanically compressed concrete. When water is added to cement, a bond will form between the particles of cement only when they are in contact, and tests have shown that the closer

this contact is the stronger the bond will be, and the closest contact can be produced only by some form of mechanical pressure. For many purposes, however, plastic concrete may be entirely satisfactory if properly made, and in many cases, especially in reinforced concrete, it is generally impracticable to use the dry rammed concrete; also in certain situations where a maximum of imperviousness is desired.

In placing such plastic concrete, however, it should be realized that at the best there is an excess of water in the mixture, and that this excessive water should not be allowed to become any greater than is practically necessary. Sloppy concrete should never be permitted under any circumstances. Excess water seems to cut down the need for mixing and it tends to make a workable mix with a minimum of cement. It also seems to facilitate the distribution of the concrete. These advantages, however, are only seeming ones. In reality the wetter the consistency the more mixing is required in order to develop a degree of stickiness in the cement which will offset the wetness, and the more cement is required in the mixture in order to maintain a certain degree of strength and the less handling the concrete can stand without suffering segregation of the particles.

The crudely manufactured early cements made a very good concrete in a dry mix, but in a wet mix a higher grade of cement is needed, a cement which will not be excessively weakened by being deposited in a very wet condition. Those who have studied modern Portland cements seem to agree on the conclusion that when the mass is not thoroughly compacted the water in the voids causes crystallization of the lime and, possibly, other ingredients of the cement and that this crystallization is detrimental to the strength and durability of the concrete. A cement in order to be suitable for use in a plastic mix must, therefore, be so constituted that this crystallization will be a minimum. This condition seems to call for a revision of the standard specifications for cement. As now drawn up these specifications do not recognize the distinction between the plastic and the dry mix. They seem to be designed entirely with reference to the dry rammed mix which was used a quarter of a century ago. It is to be hoped that some test will be devised by which the behavior of the cement in a plastic mix will be revealed so that greater uniformity will be obtained.

The appearance of laitance on the upper surface of wet concrete

is to be regarded as an indication that more or less of the best of the cementing medium has been floated to the top and thus lost to the concrete. This laitance occurs in an amount which is more or less proportional to the quantity of water used in the mix and should always be carefully removed, since it seems to be so constituted that it will not permit of a bond with work placed above it.

Porosity of the mass and weakness of cement bond seem to be among the primary conditions which result in the disintegration of concrete, but evidence seems to be accumulating that many cases of failure are to be attributed to the dissolving out of the soluble crystalline components which form in the presence of an excess of mixing water. Small channels resulting from this solution action become filled with water which expands on freezing and thus tends to hasten the disintegration of the mass.

One other factor which seems worthy of consideration is the part which may be played by the variation in kind and quality of the raw components which enter into the cement. The materials coming from the quarries are of necessity subject to variation, and in the case of some, this variation is within extremely wide limits and may easily result in a variation in the characteristics of the finished product sufficient to account for many of the failures which have occurred.

It seems clear, however, that the action of the mixing water is one of the most important elements governing the quality of concrete, and further study along this line will undoubtedly result in a modification of the present standard specifications, with a view to eliminating those cements which are unduly sensitive in the presence of water, and which show the greatest breaking down of their primary constituents in the interval between the beginning of the mixing and the attainment of the initial set.

Much work in these directions remains to be done, and progress while necessarily slow, is none the less certain. Our aim in this direction should be to produce a cement which will have all of the good features of the modern Portland, combined with all of the age-resisting and time-defying qualities of the cements of ancient Rome.

RUDOLPH J. WIG: The author might explain one way in which the conclusion regarding the undesirability of watery consistency is reached. There is one government project where there are some twenty-five or thirty structures. Similar designs and similar materials were used, but they were built at different periods, ranging

from 1893 up to the present time. In studying these structures it was found that every structure built from 1893 up to 1902 had been either wholly or partially replaced, having disintegrated when exposed to severe erosion conditions; while all of the structures built from 1902 to 1904-05 are in excellent condition today and show no erosion. The structures built from 1905 up to the present time have either been extensively repaired, or are now severely eroded. Another structure was built in three periods, one portion being built in 1901, under the supervision of an engineer who believed in very dry concrete. The second portion of the structure was built two or three years later, a new engineer being in charge who permitted the use of a little wetter concrete, in fact, it was of the mushy consistency. About five years later the first portion of the structure was so badly eroded that it had to be repaired. The repairs were made with concrete of a very wet or fluid consistency. The repaired section is now very badly disintegrated, the original work which was not repaired is badly disintegrated; the second portion which was mixed to a mushy consistency is in excellent condition, and has not been repaired.

The author was rather interested recently in examining some work being done under the supervision of the Fine Arts Commission of Washington, in which the contractor is mixing his concrete for twenty minutes. He is not doing this under compulsion, as the specifications do not require it; but he figures that the improvement in quality warrants the additional cost. The contractor who mixed the concrete for twenty minutes did so in order that he might reduce the amount of water required for proper plasticity. Hydrated lime has long been used for increasing plasticity, and the author believes it can be used with satisfaction. Similar results can be obtained by using other fine materials, or an increased amount of cement.

The author desires to make some further remarks about testing cement. Cements tests are of absolutely no value unless the samples taken are really representative of the material which is to be used. You cannot take samples with a sampling iron from the top of a bin of any depth and get material which represents the product in the bin. If samples are taken by this method, only the cement at the top is obtained and not the material three or more feet from the surface. A number of investigations have been made in coöperation with cement mills, in which sound and unsound cement was in layers in the bin and samples taken in various ways to determine satisfactory methods of sampling.

The author did not attempt in the paper to emphasize the need for a better consistency with re-inforced concrete. It is recognized that a wetter consistency must be used for reinforced than for unreinforced concrete. This may be in part compensated for by using more cement.

Major Longley emphasized the need for greater density and for using more cement in mixtures. Few engineers realize that by increasing the amount of water only one per cent at the critical point the strength of a 1-2-4 concrete may be reduced 50 per cent. Strength is not the only factor affected by the use of excess water. The porosity is greatly increased, which make it subject to rapid weathering. Increased density is obtained if a smaller quantity of water is used in the mixing.

The term "erosion" was used to cover disintegration or deterioration from internal causes such as unsound cement or frost action and external mechanical causes such as abrasion.

The angle of the chute is set rather high, perhaps higher than is necessary in some cases, in order to avoid a desire on the part of the contractor to use very wet mixtures. If the angle of the chute is very great wet mixtures will slop over. Furthermore, the steep angle of the chute will require a very high tower if the material is to be conveyed a long distance; thus the tendency will be to use wheelbarrows or buggies rather than chutes. In the author's opinion, the latter are far more preferable from the fact that by their use the concrete is deposited in smaller quantity at or near the particular point where it is to remain. Where shot into the form from a chute and worked along the form into place the fine material and laitance are worked to the outer edges and corners.

In reference to the seasoning of cement, it is the author's belief that the best cement is absolutely sound when manufactured, so that it may be taken from the mill and immediately used. The reason that it has been necessary to store cement during the past, and is in fact necessary now in most mills, is that manufacturers do not control, properly, the temperature of burning, composition and other factors in the process of the manufacture of the cement that are necessary to get it thoroughly burned and have the proper proportions of the cement mixture so that it will be sound. The best cement can be used directly from the mill and is sound without seasoning.

Perhaps this needs further explanation. Cement is unsound when it contains a certain amount of free lime or compounds of lime. As

cement is seasoned both the lime and cement compounds are hydrated. In other words, some of the very finely ground particles of the cement which would have good cementing value are hydrated and made inert. Thus all seasoning of cement is at a sacrifice of cementing material. However, when the cement has not been so carefully manufactured as to be free from free lime it is necessary to season it with a slight reduction in cementing value.

If concrete is exposed to continued seepage of water it may or may not disintegrate, depending upon the purity of the water and the condition of the concrete, particularly as to the state of carbonation of the lime of the cement.

No definite figure can be given for the amount of water required for concrete; it depends upon the materials used, particularly the gradation of the sand and the amount of water contained in the aggregates as they lie in the pile. One gentleman described very well the best consistency of concrete when he said that it should be about that of cow dung. That expresses it very well.